The Cracking of Bitumen from Canadian Alberta Tar Sands

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One of the greatest known hydrocarbon deposits in the world today is that of the Canadian Alberta Bituminous Sands. The known bituminous sand deposits are estimated to contain over 100,000,000,000 barrels of bitumen. [1]When the economic demand is high enough for gasoline the Alberta bitumen can be converted into over 35% of high anti-knock motor fuel by the cracking process. The quantity of gasoline obtainable from the known deposits of Alberta bitumen would be more than 35,000,000,000 barrels or enough gasoline to supply the present world demand for over one hundred years. The cracking of Alberta bitumen not alone yields a high per cent. of gasoline but also fuel in the form of gas and coke. The cracking of 100,000,000,000 barrels of Alberta bitumen will produce one hundred thousand billion cubic feet of gas having a high thermal value. The coke produced will amount to approximately 7,000,000,000 tons.

The Alberta bituminous sands have been noted by a number of explorers, one of the earliest being McConnell[2], who reported in the year 1890 an estimation of the bituminous sand being a minimum of 1,000 square miles in area. Ells[3] estimated the area to be a minimum of 750 square miles, whereas Dr. T. O. Bosworth[4], chief geologist of the Imperial Oil Company, estimated the area in 1919 to be 15,000 square miles. Clark and Blair[5] estimate the area of the bituminous sands to be at least 1,000 square miles as indicated by the exposure along the Athabaska river and its principal tributaries.

The first comprehensive report on the Athabaska bituminous sands is that by Ells[6] in the year 1914, when he estimated the area as being probably not less than 750 square miles. The

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[1]S. M. Blair Scientific and Industrial Research Council of Alberta. Private communication. 1926.
[2]Annual Report of the Geological Survey, 1890-91, Canada.
[3]Bulletin 281, Dept. of Mines, Canada, 1914.
[4]First Annual Report on the Mineral Resources of Alberta, 1919.
[5]Fifth Annual Report on the Mineral Resources of Alberta, 1924.
[6]"Preliminary Report on the Bituminous Sands of Northern Alberta. Department of Mines, Canada. 1914.

deposits are those of sands impregnated with heavy asphaltic hydrocarbons. Geologically the bituminous sands represent the Dakota sandstone overlying the limestones of the Devonian age. Overlying the tar sands are soft Cretaceous sedimentations. It is assumed that the tars have been derived from petroleum, probably originating in the Devonian strata, and that the petroleum flowed into the sands in a horizontal direction rather than coming from a lower surface flowing upwardly. There is justification for this assumption in the general absence of faulting characteristics in the area. The formation is that of ordinary sandstone saturated with bitumen, ranging in colour from black to gray as a function of the percentage saturation and the depth of the bed. The sandstone texture ranges from coarse to a fine silt 80% of which will pass through a 150-mesh screen. Ells in his report gives a table of the bitumen content of the sand as ranging between 8 and 20%. The average is given as between 15 and 18%. Laboratory tests from the various samples show a volume of from 15 to 25 imperial gallons per ton. An average sample collected by Ells on the Athabaska river showed a

Bitumen soluble in carbon bisulphide 18.5%
Sand 80.2%
Water 1.3%
Specific Gravity 25°C./25°C. 1.75.

The general description of the area underlaid by bituminic sand is given by Ells[1] as follows:

"The Athabaska and Clearwater Valleys constitute the chief topographical features of this area. The principal tributary streams include Christina, Hangingstone and Horse Rivers, Poplar Creek, Steepbank, Beaver, Muskeg, McKay, Ells (formerly Moose), and Tar Rivers, Wolf Creek, Calumet and Firebag Rivers. Along each of these streams, valley walls are abrupt and the zones in which drainage is effective are as a rule limited in extent. Throughout these narrow zones there is in most places a fair growth of poplar, jack pine or spruce, although a considerable percentage of such growth has been destroyed by fire, and large areas at a distance from the principal valleys are now almost covered by dense second-growth poplar and jack pine."

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"**Extent of Deposit.**—It is at present impossible to attempt an accurate estimate of the area underlain by bi-

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[1]Bituminous Sands of Northern Alberta. Department of Mines, Canada. 1924.

tuminous sand. The writer has examined upwards of 270 individual outcrops, all of which represent parts of an almost continuous deposit. These outcrops occur at intervals along the Athabaska River and its principal tributaries, for a total distance of more than 220 miles. On the Athabaska River, the most northerly exposure of apparent commercial importance occurs in Section 16, township 98, range 10. Other minor exposures are, however, seen along the Athabaska, as far as the northern boundary of township 105. The direct distance in a north and south direction through which outcrops have been noted is approximately 115 miles, and that from east to west approximately 45 miles. Extensions of the deposit under heavy overburden, particularly toward the south, will materially increase the above estimate. Having due regard to methods at present practicable for mining bituminous sand, and considering other controlling factors such as variation in quality, the area actually available for commercial development at present, probably does not exceed 1% of the above estimate. In addition to the occurrences indicated other exposures of bituminous sand have been found at points many miles to the east and west, notably on the Wabiski River, on the headwaters of Tar River, on Muskeg River, on Buckton Creek, and on Firebag River, Alberta; and on Buffalo Lake, Saskatchewan. Certain of these exposures have been examined by the writer; but if commercial development of the various outcrops in the McMurray district is found to be impracticable, it is evident that deposits in the outlying areas noted above cannot be considered as of present economic importance.

"In view of the above it will be seen that, in considering possible commercial development of bituminous sand areas, the thickness of overburden and the ground available for the disposal thereof, freedom from impure partings, uniformity and degree of enrichment, and conditions affecting transportation, may be recognized as among the principal controlling physical factors. Other factors, such as fuel supply, labour, etc., will not be discussed here."

In the report by Clark and Blair[1] on their field examination of the bituminous sands, they list the nature of the bituminous sand outcrops and their significance, the nature and variation in the types of overburden, of the sand which is impregnated with bitumen, of the contained bitumen, and also the physical

[1]Fifth Annual Report of the Scientific and Industrial Research Council of Alberta, 1924. (Edmonton.)

nature of the bituminous sand as a whole. Their conclusions are based on a detailed study and analysis of samples taken over the whole significant bituminous sand area.

The study was carried out by selecting representative outcrops from different parts of the area. A thorough examination was then made of the selected outcrop by digging a trench from the top to the bottom so that the fresh sands were uncovered. Representative samples for analysis were then taken from the individual bands and lenses of bituminous sand.

In their report the following general nature of the bituminous sands is described:

> "The general appearance of an exposure, and the superficial indications of the sort of bituminous sand it contains, can be very deceiving. It is unsafe to form any conclusion about a material that lies behind a bituminous sand exposure until the surface material has been stripped away and the fresh beds brought to view. As a general rule, the individual bands of bituminous sand contrast sharply with each other. Bands containing different percentages of the bitumen, water, and mineral matter constituents generally behave differently under the influence of weather, and the change from a bed of one material to another is thus made apparent. But it often happens that bituminous sands of widely varying bitumen content weather to the same general appearance. It is impossible to be sure of the nature of the material outcropping in an exposure without first removing the weathered surface and securing a fresh section through the beds from top to bottom.
>
> "Cross sections of ordinary bituminous outcrops present varying successions of minor strata and bands. These consist of varying grades of bituminous sand and of silt or clay. Many of the bands, particularly in the upper part of the formation, are lenticular. There is a great variation in the thickness of the lenses and also in the rapidity with which they pinch out laterally. Division into thin beds, and the occurrence of lean bituminous sand, are characteristic of the upper portion of the formation; thicker beds and richer bituminous sand characterize the lower portion of the formation. This generalization, however, has exceptions, as exposures were found where one or more strata of rich bituminous sand occurred toward the top of the formation.

"The bitumen content of the various bands appearing in an outcrop may vary from 1 to 20%, but seldom exceeds 16%. When bituminous sand is called 'rich' or 'of commercial significance,' it is meant that its bitumen content is 9% or greater. Rich bituminous sand is cliff-forming, and has a cleavage which may either be regular or parallel to the face of the exposure. It may be homogeneous and massive, or have distinct minor divisions and cross-bedding."

* * * *

"In general the bituminous sand formation consists of two main economic divisions—a lower and an upper division. This lower division immediately overlies the Devonian limestone. It is more constant in nature over the bituminous sand area than the upper division. At some points it has a thickness of one hundred feet. It has a much higher average bitumen content than the upper division and generally has a decided cliff-forming tendency. In comparison with the upper division it has remarkably few bands or lenses of clay or lean bituminous sand."

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"There appears to be little change in the nature of the bitumen contained in the bituminous sand throughout the area. It is always a heavy, dark brown, viscous oil, and with few exceptions has a specific gravity between the values of 1.010 and 1.035 (25°C./25°C.). A few values as high as 1.050 were found, but these are in all probability to be accounted for by weathering. The bituminous area accessible from Ells River seems to be exceptional as regards the gravity of the bitumen. Specific gravity values from the bitumen of samples collected from this locality ranged from 1.005 to 1.015."

"The sulphur content of the bitumen is consistently high, and ranges from 4.5 to 5%."

One part of the bituminous sand area that is recorded in the report and is apparently considered to be one of the types that appear favorable to commercial development, has an overburden of sand and clay varying in thickness from three to six feet. This is underlain by a thickness of approximately sixty feet of bituminous sand strata. The bituminous sand is essentially uniform in nature, and is massive, rich, soft and homogeneous. Very few partings of lean material occur. The average bitumen content is about 12.5%. The water is from 3 to 6%. The sand has from 3 to 9% retained on a 100-mesh sieve,

from 80 to 87% on a 200-mesh sieve, and from 8 to 14% passes a 200-mesh sieve. The specific gravity of the bitumen varies from 1.020 to 1.025.

MINING OF THE BITUMINOUS SAND

The simplest way of mining the bituminous sand apparently is the steam shovel method. It has been estimated by several engineering concerns that the Alberta bituminous sand could be steam-shoveled at approximately 10c a ton. No special difficulties in steam-shoveling the bituminous sand are present for it is purely a question of passing through a viscous tar impregnated with relatively fine sand. The bituminous sand used by the Industrial Research department was unloaded from flat cars by the use of a steam shovel and there was no tendency whatever of the material sticking to the shovel.

Clark and Blair determined the possibility of draining the bitumen from the bituminous sand in a similar method to that which is followed in the so-called oil field of Pechelbronn, Alsace. A shaft was sunk into the bituminous sand for the double purpose of determining the possibility of draining the bitumen, and also of procuring samples of the bitumen sand for comparison with that which had been procured from the outcrops by trenching. The nature of the material was found to check with that obtained by trenching but as far as this shaft was concerned there was no tendency whatever for the bitumen to drain out of the sands, during a period of three months' observation. It is evident that the material is very different from that in Alsace; but as is pointed out in the report, it is not proven that this condition exists over the whole bituminous sand area.

RECOVERY OF THE BITUMEN FROM THE BITUMINOUS SAND

The bituminous sand formation underlies a great area in the northern part of Alberta. Attention is at present focused largely about the McMurray District at the junction of the Athabaska and Clearwater rivers, and the area is about 300 miles from Edmonton, which is the closest large industrial centre. When the bituminous sand is exploited for an industrial purpose in which sand is of no value, an economic separation of the bitumen from the sand must be provided. When one considers that roughly 80% of the weight of the material consists of sand the freight rates make its shipment impracticable from an economic point of view.

The methods which have been proposed for the handling of the bituminous sands are:

1. Thermal distillation by external heating.
2. Thermal distillation by partial combustion of the bituminous sand inside the retort, either by upward or downward draft method.
3. Combustion gases passing through the bed of bituminous sands within the retort.
4. Use of solvents such as petroleum distillates, etc.
5. Hot water, steam or hot water and steam combination.
6. Use of solutions of sodium silicate, alkalis, such as sodium hydroxide or alkali salts.
7. Use of acids such as dilute sulphuric.

The above methods can all be worked out as technical successes, but the economic side naturally plays the major role.

Mr. T. Draper, of the Alberta Oil and Asphalt Co., is one of those who have carried out actual experiments in thermal distillation of the bituminous sand as mined.

The solvent method of tar extraction has been used in the United States and found to be too expensive. Mr. Roland B. Day[1] has an interesting paper in this regard on the economics of "Oil for Canada from Her Tar Sands."

A large amount of work has been carried out on methods of separating the bitumen from the sand by the use of dilute solutions and hot water. It is reported that attempts have been made to separate the bitumen from the bituminous sands **in situ** by means of hot water and steam. Experiments have been carried out in California on methods of separating oil from sand by the use of hot water.

Dr. Clark[2] has done a great deal of work on the separating of the bitumen from the bituminous sands by the use of dilute solutions. He first used a soap solution, and also experimented with sodium hydroxide, sodium carbonate, and sodium silicate. All of these solutions separate the bitumen from sand quite cleanly. He also found when adding a small proportion of kerosene to the bituminous sand that a better separation took place. However, the method which appears to be the most promising commercially is the use of a solution of hot sodium silicate. He mentions Fyleman's process of tar separation from sand as shown in British patent 163,519 of 1920, and

[1]Oil and Gas Journal, Vol. 24, P. 21 (1925).
[2]Reports No. 1 and 3, of the Scientific and Industrial Research Council of Alberta, (Edmonton.)

Canadian patent 203,676 of 1920, where dilute solutions of alkali salts, hydroxides, soap or other froth-forming substances, or dilute acids are recommended.

The separation principle worked out by Clark[1] has since been developed and applied on a semi-commercial scale by Clark and Blair[2] in a plant where the bitumen is removed from the sand in a continuous operation. During the early part of 1925 they separated the bitumen from over 500 tons of bituminous sand. The operation consists in obtaining an intimate mixture of the bituminous sand and the dilute solution of sodium silicate; the whole mass is then raised in temperature to near the boiling point of water, and in that state is passed quickly into large reservoirs of hot water. Here the bitumen actually separates from the sand and rises to the top of the water from where it is removed by mechanical means. The sand falls to the bottom of the water from where conditions are prepared for its continuous removal.

The average analysis of 75 plant samples was as follows:

Crude Separated Bitumen	
Water	28%
Bitumen	65%
Sand	7%
Sand Tailings	
Bitumen	2%

The complete separation was hindered to a certain extent by the lumps of weathered material which when broken up contaminated both the bitumen and the sand tailings. These lumps, however, would not be encountered to an appreciable extent where large amounts of the material were being freshly mined.

The sodium silicate required for the separating solution would cost less than 5c per ton of bituminous sand, and the whole separation operation could apparently be carried through at a low cost, probably not more than 50c per ton of bituminous sand separated.

NATURE OF THE BITUMEN IN THE BITUMINOUS SAND

Dr. Lehmann, Dr. Sayers and others at the University of Alberta have carried out ultimate analysis of the bitumen and have also separated and characterized some of the lighter hydrocarbons which are in the bitumen.

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[1]Reports No. 1 and 3 of the Scientific and Industrial Research Council of Alberta. (Edmonton.)
[2]Report No. 6 of the Scientific and Industrial Research Council of Alberta. (Edmonton.)

Ells reports an average analysis of the bituminous sand as follows:

CC Distilled Over	Temperature °C	Specific Gravity
2.5	0-110	0.85
73.0	110-275 chiefly between 250-275	0.88
17.5	300-330	0.91
2.5	330-360	0.96

The recovered sand consisted of clear or milky quartz angular to well-rounded particles. The sand appeared to have been rounded by means of moving water. The sand analysis follows:

Oxides	Percent
Silica	95.5
Aluminum	2.25
Calcium	0.50
Iron	0.35
Magnesium	0.23

DRY DISTILLATION OF TAR SANDS

When a block of tar sand is heated it becomes a plastic mass. However, the sand does not drop out due to the changed viscosity of the oil. The sand is in too fine a state of division.

Samples of tar sand were distilled to dryness in a retort. The following analysis by Kelso[1] is typical of the oil recovered from the tar sand by distillation:

Distilled Oil at Atmospheric Pressure from Tar Sand
Baume Gravity 19.5

Percent Distilled Over	Be. Gr.	°C.
9.7	51.6	70-150
9.1	36.5	150-230
4.9	25.0	230-260
13.3	24.0	260-300
18.6	23.0	300-325
14.0	18.5	325-350
23.0	15.5	350-380
Loss 7.4		

[1]Second Annual Report Scientific and Industrial Research Council, Alberta. (1920.)

CRACKING OF BITUMEN DERIVED FROM ALBERTA TAR SANDS

A representative Alberta bitumen used during the present tests was obtained through Dr. K. A. Clark and Mr. S. M. Blair of the Scientific and Industrial Research Council of Alberta, Edmonton, Canada, and it was obtained from the sand by the water separation as previously described in this report.

Analysis of Alberta Tar

Spec. Grav.	1.031
Sulphur	5.1%
Water	2.5%
Coke (by wt.)	25.0%

A. S. T. M. Distillation

Percent Distilled Over	Temperature °F.
5	460
10	540
15	490
20	505
25	572
30	590
35	605
40	608
45	655
50	640
55	638
60	618
65	595
70	584
75	583
77	658

The above type of Alberta tar was subjected to cracking conditions of 90 lbs. pressure and temperature average of 750°F. The mode of cracking was to produce a cracked distillate, incondensable gas and coke. The Alberta tar lends itself particularly to cracking at low temperature and pressure, producing a superior motor fuel having an aromatic equivalent of 33%.

The pressure distillate oil produced by the cracking reaction represented 56% of the Alberta tar treated. The following analysis of the pressure distillate oil was carried out by means of the Hempel column mode of fractionation:

Bituminous Sand Outcrop on the Athabaska River

Pressure Distillate Oil

A. P. I. Gr.	38.8
I. B. P.	78°F.
Unsaturated Hydrocarbons	40%

Percent Distillate Over	Temp. °F.	A. P. I. Gr. Fractions
5	123	84.8
10	158	79.4
15	192	69.1
20	224	62.0
25	254	56.0
30	272	51.3
35	290	49.2
40	307	46.3
45	334	43.2
50	357	40.4
55	382	37.3
60	408	34.2
60.6	410	
64.8	430	

TREATMENT OF PRESSURE DISTILLATE OIL TO PRODUCE MARKETABLE GASOLINE

The pressure distillate is agitated with eight pounds of 66° Baume sulphuric acid per barrel of oil. The sludge acid is drawn off and may be used in subsequent treatments until practically all the acid has been utilized. After the removal of the sludge acid the oil layer is treated with water. The water layer is drawn off and the oil layer subjected to a one percent by volume of 10° to 16° Baume plumbite solution. The plumbite solution may be used until exhausted in subsequent treatments of fresh pressure-distillate oil. The acid, water and plumbite treated oil is then pumped to the steam stills and subjected to light fire and heavy steam distillation. The gasoline fraction may be further improved in odor, by subjecting it to a one percent solution of sodium hydroxide, or a dilute plumbite solution.

The gasoline obtained by the above treatment is water-white, stable, negative to the doctor and corrosion tests. The gasoline is also high in aromatic hydrocarbon content. The analysis of the gasoline follows:

A. P. I. Gr.	50.8
Init. B. P.	107°F.
End Point	437°F.
Unsaturated Hydrocarbons	27.2%
Aromatic Hydrocarbons	24.7%
Naphthene Hydrocarbons	12.3%
Paraffin Hydrocarbons	35.8%

A. S. T. M. Distillation Analysis

Percent Distillate Over	Temp. °F.
10	169
20	206
30	238
40	266
50	289
60	313
70	336
80	364
90	396
End B. P.	437

The gasoline yield represents 36.3 percent of the Alberta tar cracked.

FURNACE OR GAS OIL

After the steam distillation of the pressure-distillate oil there is a residue left which makes a fine furnace oil, gas or cracking oil. The pressure distillate residue or bottoms analyzed as follows:

A. P. I. Gr.	16.6
I. B. P.	440°F.
End Point	760°F.

Percent Distillate Over	Temp. °F.
10	465
20	480
30	496
40	512
50	532
60	555
70	590
80	640
90	735
99	760

INCONDENSABLE GAS

The cracking of Alberta tar produced a relatively high yield of gas suitable for fuel or chemical derivative purposes. The quantity per barrel (42 gallons) of tar cracked is 1000 cubic feet. The B. T. U.'s per cubic foot of gas approximates 1000, hence would be a fine fuel for industrial uses.

COKE

The coke yield from the cracking of Alberta tar is high and represents approximately 139 pounds per barrel treated. The B. T. U.'s per pound of coke produced approximates 15,000.

SUMMARY OPERATING DATA

	A. P. I. Gr.	Percent of Charge
Alberta Tar	5.8	
Pressure Distillate Oil	38.8	56.0
Water		1.7
Coke 139 lbs. per barrel		
Uncondensable Gas 1000 cu. ft. per bbl.		
Gasoline	50.8	36.3
Init. B. P. 114°F.		
End Point 437°F.		
Gas Oil (Press. Dist. Bottoms)	16.6	17.6
Operating Pressure 90 lbs.		
Liquid Temperature 750°F.		
Furnace Temperature 1450°F.		